Change Monitoring of Antarctic Sea Ice Using NSCAT Dual-Polarized Backscatter Measurements

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Abstract – Polar sea ice characteristics and the timing of seasonal transitions are important parameters in the study of polar processes and climate changes. NSCAT Ku-band active microwave observations of the Antarctic sea ice cover are described in this article with emphasis on the monitoring of ice covers through the change of Ku-band backscatter signatures. A simple backscatter and polarization ratio threshold algorithm was used to discriminate sea ice and open water with NSCAT dual-polarized backscatter data. The estimated backscatter of classified sea ice pixels is illustrated. The new first year (FY) and pancake sea ice have a backscatter level similar to those of corresponding ice types in the Arctic, although the ice growth mechanisms are quite different. The significant changes of ice backscatter in the Weddell Sea correlates well the timing of fall freeze-up. This should provide a useful large-scale estimate of the dates of freeze-up. A more extensive validation of the potential of this dataset is definitely suggested.

INTRODUCTION

In this paper, we illustrate the potential of using spaceborne Ku-band scatterometer observations for monitoring the seasonal change of Antarctic sea ice cover. The NASA Scatterometer (NSCAT) [1], launched on the Japanese Advanced Earth Observation Satellite (ADEOS) in August 1996, is a Ku-band (13.995 GHz) microwave radar, designed to measure global ocean wind fields. Although the NSCAT mission was terminated at the end of June 1997 due to the failure of ADEOS solar panel, it has acquired a large enough dataset to enable a closer examination of active Ku-band radar signatures of Antarctic sea ice from summer melt to austral winter.

The seasonal cycle of growth and decay of the ice cover is dependent on insolation and the variability of atmospheric and oceanic forcings on interannual and decadal time scales. The time series of ice extent derived from recent satellite passive microwave record (1978-1996) show an almost 3%/decade decrease and a 1.3%/decade increase in the area of the ice cover in the Arctic and Antarctic since 1978 [3]. NSCAT is the first active microwave sensor, with comparable spatial and temporal coverage, to

provide a complementary view of the entire sea ice cover and may serve to improve our understanding of the estimates of ice concentration and areal extents from satellite passive microwave data [3, 4].

NSCAT DATA: SEPTEMBER 96-JUNE 1997

NSCAT operates six fan beam antennas illuminating two single-sided 600 km swaths [1]. The fore- and aft- antennas operate at vertical polarization, while the mid-beam antennas acquire vertically and horizontally polarized backscatter. The ratio of the vertically and horizontally polarized returns (polarization ratio) at incidence angles above 40 degrees has been found to be an effective discriminator between sea ice and open water samples [6]. A simple algorithm for ice/water classification was developed using the polarization ratio and backscatter intensities (interpolated to 50 degree incidence angle) [6]. We apply this ice/water classifier to NSCAT data sampled to a 25 km Special Sensor Microwave/Image (SSM/I) grid based on the locations of cell centers. The polarization ratios are averages of observations above 40 degree incidence acquired by the middle beam from multiple satellite passes. We also use the near-simultaneous NSCAT data from all antenna beams and all incidence angles to estimate the backscatter on a 12.5 km SSM/I grid using the following linear backscatter model

$$\sigma_0(dB) = A + B(\theta - 50) \tag{1}$$

where θ is the incidence angle in degrees. The coefficients A and B are estimated using the least-squares criterion with the squared-difference between every NSCAT measurement and the linear model weighted by the areal fraction of the σ_0 cell falling inside the 12.5 km x 12.5 km SSM/I bins. The average polarization ratios and the estimates of A are subsequently used to classify sea ice and water on the 25 km SSM/I grids. Because this algorithm uses only NSCAT mid-beam polarization ratios above 40 degree incidence, it requires about 3 days of data to complete the classification of the entire Arctic region because of reduced spatial coverage.

Figure 1 illustrates the Ku-band backscatter images (A in dB) of Antarctic sea ice from September 1996 to June 1997. From September through January, the ice extent decreases with rising air temperature. The ice extent reached a minimum in early February with a total decrease of about 20 x 10^6 square km from the maximum.

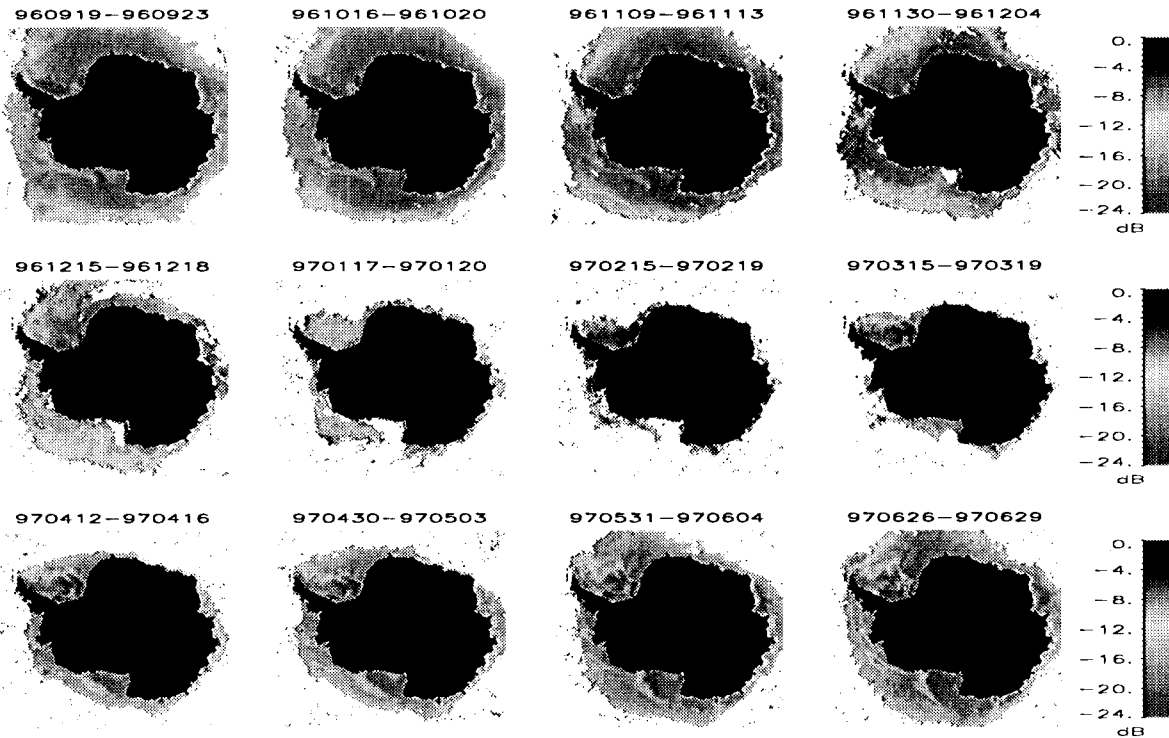Ice Edge Defined by Polorization Ratio and Backscatter

Figure 1. Changes of Ku-band backscatter (A in dB) from September 1996 through June 1997.

Fall freeze-up started in February as suggested by the images in the middle panels. Before fall freeze-up, most portions of the ice cover are first year (FY) sea ice and attain a medium to low backscatter in the range of -12 to -24 dB. The exceptions are areas of pancake ice and deformed FY ice (mostly near the ice edge), which have a stronger backscatter. For instance, it is observed that the backscatter from the sea ice cover in the Ross Sea tends to increase by a few dB during surface melt, likely due to rough surface scattering from the edges of pancake ice and deformed ice surfaces created by the surface rafting of waves. The fall freeze-up was signified by an increasing ice extent toward the end of June. The new FY ice has a low backscatter level (typically less than -14 dB) similar to what was observed from Arctic FY ice, although the mechanisms for ice formation are quite different between both polar regions.

There were several polynyas detected in the NSCAT measurements. (Polynya is an area of open water in the ice pack.) The most noticeable one is the Ross Sea polynya appeared in late November in the coastal Ross Sea. Polynyas are the regions with significant air and sea heat flux exchanges and the areas with significant biological activities. It is suggested that the polynya is created by the upwelling of warmer bottom sea water or the winds

driving the thin new ice away the polynya. A successful detection of polynyas in the NSCAT images suggests further studies for the interaction of ice cover, wind, and ocean convection with Ku-band scatterometers.

However, if the air temperature is reasonably low, the opening of ice cover, created by a divergent ice motion, driven by winds or currents, can be quickly filled up by new grown ice. This was observed in the NSCAT images of coastal Weddell sea waters from February through June 1997. Due to the Weddell sea gyre, the older FY or multi-year sea ice with a higher backscatter was driven toward the ice edge from the coastal areas. The opening was quickly covered by new FY ice with a backscatter typically lower than -15 dB. We illustrated the time series of backscatter at eight points in the Weddell Sea (Fig. 2) - the location of these points are indicated by the SSM/I grid coordinates on the top of each panel. These eight points are located from the central Weddell Sea (SSM/I y=1375 km) to near coast (SSM/I y=937.5 km). There is a significant increase of backscatter from about -20 dB to -10 dB in late January, coinciding well with the timing of fall-freeze up. A similar increase was observed by [5] for Arctic sea ice during fall freeze-up in ERS C-band Synthetic Aperture Radar (SAR) images. It is speculated here that the new snow cover with an average snow grain
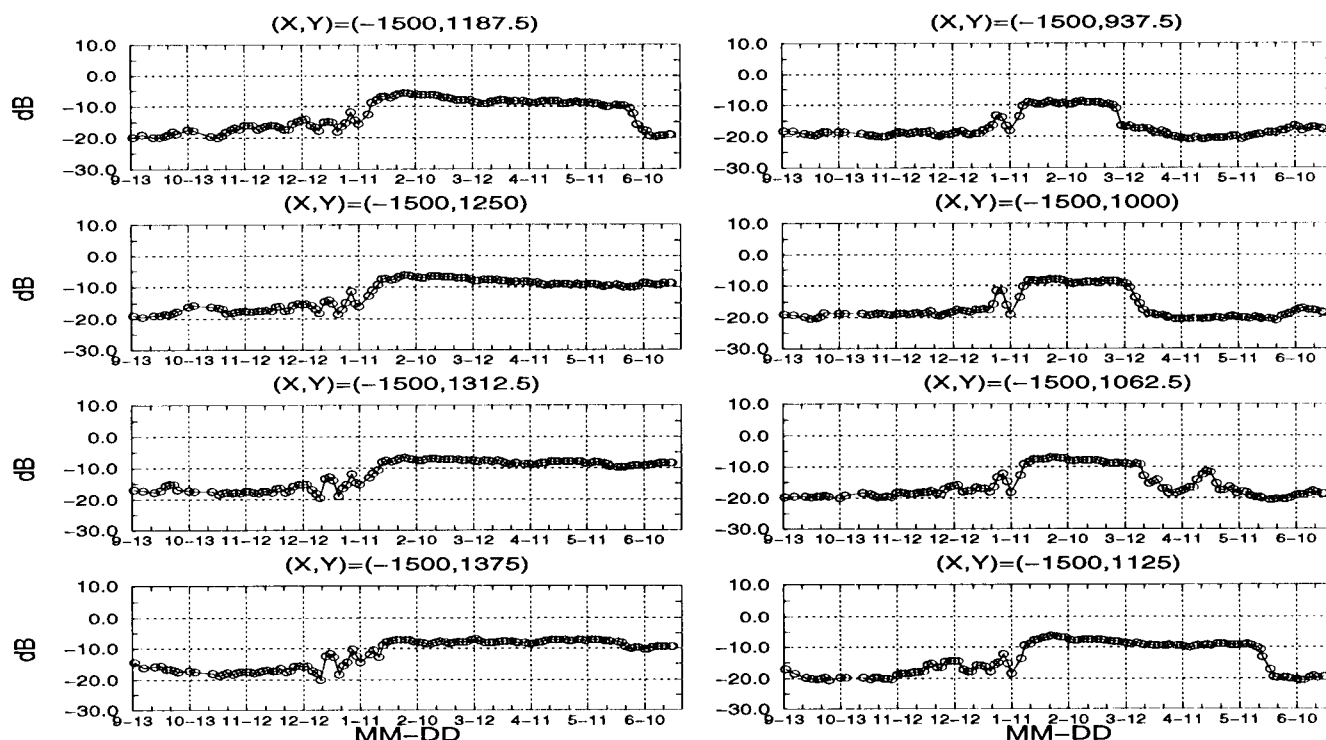
Figure 2. Temporal variations of Ku-band backscatter (A) at eight selected locations in the Weddell sea. The location of each pixel for σ_0 tracking is indicated on the top of each panel by the SSM/I grid coordinate (x,y). The units of x and y are km.

size of a few millimeters [2] has contributed to this significant increase. Another significant backscatter change was marked by a decrease of as much as 10 dB in five panels in Fig. 2. This was caused by the change of backscatter from older ice to lower backscatter from new ice.

SUMMARY

The NSCAT observations of Antarctic sea ice are illustrated in this article. The level of backscatter has a reasonable correspondence with several ice types. Seasonal transitions of ice extent and ice cover are clearly noticeable in the time series images of Ku-band backscatter from September 1996 to June 1997. Fall freeze-up in the Weddell Sea was marked by a significant increase in backscatter level. The impact of ice motion on region ice growth and signatures was also evident. Further research on the interpretation of active scatterometer measurements is clearly desirable.

ACKNOWLEDGMENTS

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